

FESHM 5031.7: MEMBRANE CRYOSTATS

Revision History

Author	Description of Change	Revision Date
Michael Geynisman Mark Adamowski John Anderson Jr. David Montanari Michael White	<ul style="list-style-type: none"> • Added References Section • Updated requirements for quality control, including pressure test. Removed references to 10CFR851. • Removed requirement for PE being employed by a company nonaffiliated with Fermilab or CERN. • Modified language to match requirements of 10CFR851 • References to equivalency between EU and US structural standards • Clarification for gas pressurization of the insulation space • Clarification for the extent of required documentation • Replace “Guidelines” with “Requirements” • Removed reference to MOU between CERN and Fermilab 	April 2020
Michael Geynisman	<ul style="list-style-type: none"> • Modifications for the pressure test requirements to allow both, pneumatic and hydrostatic testing • Modifications per Lab-wide review comments, including: <ul style="list-style-type: none"> - Grammatical improvements - Addressing potential spill due to piping penetrations below the liquid level - Listing all loads to the support structure - Clarifying attachment of the top plate to structural support 	November 2015
David Montanari, Barry Norris, Michael Geynisman, Elaine McCluskey	<ul style="list-style-type: none"> • Initial release 	April 2015

TABLE OF CONTENTS

1.0	INTRODUCTION	3
2.0	SCOPE	3
3.0	DEFINITIONS.....	4
4.0	SPECIAL RESPONSIBILITES.....	6
5.0	POLICY AND REQUIREMENTS.....	6
6.0	ENGINEERING NOTE.....	10
7.0	REFRENCES.....	10

1.0 INTRODUCTION

This chapter defines the procedure for the design, fabrication, erection, quality control, testing, maintenance, repair, and operation of cryogenic metallic membrane cryostats commonly referred to as membrane cryostats. Membrane cryostats contain cryogens, in both gas and liquid state, and therefore possess the normal hazards associated with a cryogenic device including a potential pressure hazard. Membrane tank technology has been used in liquefied natural gas (LNG) stationary and transportation storage across the globe for the last half-century. Membrane cryostats are used at Fermilab for neutrino physics using liquid argon (LAr) as the contained cryogenic fluid. Membrane cryostats may also contain nitrogen or other inert fluids.

Membrane cryostats differ from conventional single shell or vacuum jacketed cryogenic vessels, which fall under the scope of Fermilab Environment, Safety, and Health Manual (FESHM) 5031 or 5031.5. In a membrane cryostat, the inner metallic membrane is responsible for leak tightness of the contained fluid while an external structure is responsible for bearing all loads from the structure self-weight, hydrostatic pressure, as well as internal or external gas pressure. The defining feature of membrane cryostats is that all forces are transferred between the membrane and the structural support through load-bearing insulation.

Sound engineering practice requires that guidance from national and international consensus codes be used for the design, fabrication, erection, quality control, testing, maintenance, repair, and operation of membrane cryostats whenever applicable. In addition, the engineering process described in the Fermilab Engineering Manual shall be applied to all aspects of the membrane cryostat. A recommended practice is to incorporate Cryogenic Safety Panel members in the reviews required by the Engineering Manual to assist with identifying FESHM 5031.7 and/or code-conflict issues early in the engineering process.

If a conflict or other discrepancy is identified between the chosen design codes and other applicable national/international standards, then guidance from the Fermilab Cryogenic Safety Subcommittee shall be sought as early as possible. The Cryogenic Safety Subcommittee is responsible for maintaining this chapter to include the current understanding of best practices for membrane cryostats.

Risk assessments shall be used to guide design, fabrication, erection, quality control, testing, maintenance, repair, and operation of cryogenic metallic membrane cryostats following the principle that hazards to personnel and capital equipment are to be minimized.

This chapter also specifies the procedure for review and approval of membrane cryostats.

2.0 SCOPE

The chapter applies to any metallic membrane cryostat containing gas or liquid argon, nitrogen or other inert fluids as defined below, which is designed, installed or operated at Fermilab or Fermilab-leased space, regardless of size, shape, site of installation, duration of use, origin of manufacture, operational location, or previous use at Fermilab or other facilities.

This chapter does not apply to cryostats or vessels, which use components of membrane tank technology without formation of a metallic membrane cryostat in whole, e.g. gas storage membrane systems per FESHM 5031.5.

3.0 DEFINITIONS

Membrane: A metallic film, or metallic primary container, separating the insulation from the liquid or gas contained in the membrane tank. Also called Primary Membrane.

Membrane cryostat: Integrated assembly, wherein a foam-insulated metallic membrane formed of prefabricated panels containing the cryogen is integrated within a structural support. The load exerted by the liquid head and the gas pressure is transferred from the metallic membrane to the structural support through the load-bearing insulation. The insulation space is purged with gaseous argon or nitrogen at a pressure within the limits defined by the membrane designer/manufacturer.

Support structure: A metallic or concrete structure (steel plates and beams, concrete, or any other type) designed, constructed, quality controlled, tested, maintained, and repaired per governing structural standard, e.g. American Institute of Steel Construction ANSI/AISC 360, Eurocodes (EN 1990-1999 series), and/or American Concrete Institute ACI 318, to withstand the loads from weight, internal and external pressures transferred through the metallic membrane and load-bearing insulation to the structural support.

Secondary barrier: A film embedded within the insulation capable of containing the liquid in case of a spill from the primary membrane. The secondary barrier is only present at the bottom and along the sides. It is not present on the roof.

Vapor barrier: A barrier that prevents external moisture from entering the insulation space.

Design Pressure: The pressure with the design temperature, used to determine the physical characteristics of the vessel components. Design pressure is defined as the maximum differential pressure permissible at the top of a tank when the tank is in operation.

Maximum Allowed Operating Pressure (MAOP): Maximum pressure at the top of the vessel at which the vessel can be operated at (without lifting the pressure relief device). The MAOP can be equal to but cannot exceed the design pressure.

Set Pressure: The inlet gauge pressure at which the pressure relief device is set to open. The set pressure shall not exceed MAOP.

Accumulation: The pressure difference between the cryostat pressure during discharge through the pressure relief device and the cryostat MAOP (internal or external).

Test Pressure: The pressure used for leak testing of the vessel at room temperature. This pressure shall be equal to or greater than the MAOP.

Maximum Allowed Pressure Accumulation: The pressure difference between the test pressure and the MAOP for the vessel. Some examples: With a test pressure equal to MAOP, the allowed accumulation is 0%. With a test pressure at 110% of MAOP, the allowed accumulation is 10%.

Maximum Design Liquid Level: Maximum liquid level that will be maintained during operation of the cryostat that is used to determine required loads for the support structure.

Codes and Standards: Membrane cryostat technology utilizes containment at pressures that fall outside the scope of the pressure vessel standards American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII and EN13445. Furthermore, a number of United States (US) and international codes, standards and recommended practices apply to the design, fabrication, erection, quality control, testing, maintenance, repair, and operation of the membrane cryostats, or particular parts of them. A separate document attached to this FESHM chapter, “*Requirements for the Design, Fabrication, Erection, Quality Control, Testing, Maintenance, Repair, and Operation of Metallic Membrane Cryostats*”, has been developed by the Fermilab Cryogenic Safety Subcommittee. The “*Requirements*” is an integral part of this chapter and references the current understanding of best international practices in the design, fabrication, erection, quality control, testing, maintenance, repair, and operation of membrane cryostats. The “*Requirements*” discusses the applicability and use of the specific codes, standards and recommended practices while recognizing that suppliers of the membrane cryostats are regulated by their respective international standards.

Engineering Note: A form TA5031.7 supplemented with written analysis demonstrating that a given membrane cryostat satisfies the requirements of this chapter.

Qualified Person: A qualified person is a person who, by possession of a recognized degree or certificate of professional standing, or who, by extensive knowledge, training and experience, has successfully demonstrated the ability to solve or resolve problems relating to the subject matter and work.

Cryogenic Safety Panel: A panel specifically assigned by the Cryogenic Safety Subcommittee to membrane cryostat reviews.

Exceptional Vessel: A vessel within the scope of this chapter which does not fully meet the requirements of this chapter and the “*Requirements*” referenced in the policy statement. The Engineering Note originator, in consultation with the Cryogenic Safety Panel, will make the determination whether the vessel needs to be considered exceptional. All exceptions require engineering analysis and justification be added to the engineering note.

4.0 SPECIAL RESPONSIBILITIES

The Division/Section Head or Project Manager (D/S/P) who controls the ownership of the metallic membrane cryostat is responsible for carrying out the requirements of this chapter. The D/S/P, or designee, shall certify compliance of the membrane cryostat with this chapter by signing the Engineering Note following review and approval by the Cryogenic Safety Panel. The original Engineering Note shall be placed into the laboratory engineering document management system.

The Cryogenic Safety Subcommittee may propose appropriate modifications to this chapter as necessary. Cryogenic Safety Panels shall arrange for the review of required Engineering Notes by qualified person(s) and verify that the membrane cryostat meets the requirements specified in this chapter, as well as any other FESHM chapter relevant to the design, fabrication, erection, inspection, examination, testing, installation, maintenance and operation of the membrane cryostat.

5.0 POLICY AND REQUIREMENTS

The metallic membrane cryostat constitutes a complete low-pressure vessel, which provides for leak tightness by the membrane and pressure containment by the support structure. All existing and new metallic membrane cryostats shall conform to the requirements of this FESHM chapter.

- 5.1 Policy:** The design, fabrication, erection, quality control, testing, maintenance, repair, and operation for all metallic membrane cryostats shall be in accordance with this chapter and the “Requirements”.
- 5.2 Design:** The design standard(s) shall be declared and accepted by the Cryogenic Safety Panel at the beginning of the design process. The design pressures and temperatures of the membrane cryostat shall be established per the chosen design standard(s). The design pressure for the membrane cryostat shall then be declared as the maximum pressure permissible at the top of the cryostat. The maximum differences in internal and external pressures, both for pressure and vacuum scenarios, shall be documented in the Engineering Note.

The material chosen for the secondary barrier shall be suitable for the design temperature. Pressurization of the secondary barrier is not possible due to its configuration. Flow rate and pressure of the gaseous purge in the insulation shall be defined by the membrane cryostat manufacturer.

- 5.3 Risk Assessment:** A risk assessment shall be prepared for each membrane cryostat and shall be reviewed as early as possible in the design stage by the Cryogenic Safety Panel and Fermilab Structural Authority Having Jurisdiction (AHJ). The risk assessment shall consider all risks that occur during the lifetime of the membrane cryostat including design, fabrication, erection, quality control, testing, maintenance, repair and operations. All reasonable and practical steps shall be taken to minimize the overall risk posed by the membrane cryostat. The methodology

for risk assessment should be per Fermilab Engineering Manual, FESHM 5032 “*Cryogenic System Review*”, and relevant standards referenced in Section 3 of the “*Requirements*”.

- 5.4** *Pressurization*: If the membrane cryostat membrane or insulation spaces can be pressurized beyond its design pressure, either internally or externally, either intentionally or inadvertently, then pressure relief device(s) shall be included in the design. Unless excluded below, pressure relief devices shall comply with requirements of ASME Boiler and Pressure Vessel Code, Section VIII.
- 5.4.1.** Pressure relief device(s) shall be selected and sized such that the membrane and insulation space pressures do not exceed the MAOP and maximum allowed accumulation.
- 5.4.2.** Pressure relief device(s) with a relieving pressure under 15 psid are not required to be ASME BPVC VIII code-stamped.
- 5.4.3.** All pressure relief devices shall be stamped with device capacity in air flow units (or orifice area and discharge coefficient) and have a functional test documenting open and reseal pressures if applicable. For each pressure relief device, a picture of the nameplate (showing capacity), functional test report and material quality certificates shall be included in the Engineering Note. Flow capacity parameters for the model and size of the pressure relief device shall be certified (e.g. testing at an ASME Performance Test Codes (PTC) 25 facility or equivalent).
- 5.4.4.** Calculations of pressure relief device sizing shall be included in the Engineering Note. ASME BPVC VIII Div. 1 does not directly contain all the necessary guidance to size pressure relief devices for membrane cryostats. Additional guidance from the following standards shall be considered for the sizing, selection, and installation of the pressure relief devices.
- American Petroleum Institute (API) 520 *Sizing, Selection, and Installation of Pressure-Relieving Systems*
 - Part I Sizing and Selection
 - Part II Installation
 - API 521 *Guide for Pressure-Relieving and Depressuring Systems*
 - API 2000 *Venting Atmospheric and Low-Pressure Storage Tanks (Nonrefrigerated and Refrigerated)*
 - Compressed Gas Association (CGA) S-1.3 *Pressure Relief Device Standards Part 3 Compressed Gas Storage Containers*
- 5.4.5.** A list of all potential means of pressurization shall be compiled. Consideration shall be given for relief of over-pressure from all possible sources, including release of gases or fluids (by design or by accidental rupture of internal components), heat, fire, connected gas or liquid sources, etc.

- 5.4.6.** Pressure relief devices used on membrane cryostats shall be periodically inspected and tested as required by FESHM 5031.4, *Inspection and Testing of Relief System*.
- 5.4.7.** Prior to putting the membrane cryostat in service, all pressure relief devices shall be installed, and the documentation requirements satisfied.
- 5.4.8.** Installing a control valve(s) sized to protect from pressurization above all likely operating conditions and set below the set pressure of the pressure relief device(s) is a recommended practice to provide an additional layer of safety and prevents unnecessary actuation of the pressure relief device(s). It is recommended that venting control valve(s) fail to the Normally Open position.
- 5.5** *Vacuum:* The metallic membrane cryostat shall be protected from every source of external pressurization. External pressurization scenarios shall be listed and discussed in the Engineering Note for the metallic membrane cryostat. When the cryostat can be evacuated or pressurized externally, for example from gaseous purge in the insulation space, relative to atmosphere or secondary barrier beyond its design differential pressure, either intentionally or inadvertently, vacuum relief device(s) shall be included in the design for all external pressurization scenarios. External pressurization of the membrane from gaseous purge in the insulation space should be protected below membrane's external pressure rating with pressure relief devices installed at the purge source.
- 5.6** *Piping penetrations:* The penetration design analysis shall include verification that forces and moments applied by the nozzle to the support structure vapor barrier are within the allowable limits specified by the support structure designer. Similarly, the penetration design analysis shall include verification that forces, and moments applied by the nozzle to the membrane are within the allowable limits specified by the membrane designer. The scope of the membrane cryostat chapter ends at the first weld or flange outside the support structure. Assemblies or piping connected to the membrane cryostat are required to meet requirements of other relevant FESHM chapters.
- 5.7** *Piping penetrations below the liquid level:* The design of the metallic membrane cryostat shall address potential for uncontrolled spills of liquid into the enclosure. Specifically, any side or bottom penetrations shall be reviewed for spill prevention early in the design stage by the Cryogenic Safety Panel. The scope of the membrane cryostat chapter ends at the first weld or flange at the outlet of the safety shutoff valve. The safety shutoff valve(s) should fail to the Normally Closed position.
- 5.8** *Membrane Inspection:* 100% of welds shall be visually inspected by a qualified person and the membrane shall be leak checked to bubble tightness or better per accepted industry practice. If ammonia leak testing method is required by the Codes and Standards applied to the membrane, then alternative accepted industry practices (e.g. helium leak checking) with equal or greater

detection sensitivity may be substituted for ammonia leak testing.

5.9 Test: In order to verify leak tightness of the membrane and integrity of the support structure, the membrane cryostat shall be subjected to an integral pressure test as required per “Requirements”.

5.10 Documentation:

5.10.1. The documentation for the membrane cryostat shall be described in the Engineering Note to demonstrate compliance to the requirements of this chapter, including the following:

- Design drawings, sketches, and calculations.
- Examinations and inspections of materials, in-process fabrications, nondestructive tests, and acceptance test by qualified personnel.

Documentation, traceability, and accountability must be maintained for the membrane cryostat, including descriptions of design, pressure conditions, testing, inspection, operation, repair, and maintenance.

5.10.2. An Engineering Note for the metallic membrane cryostat, including support structure, shall be prepared by a qualified person for each membrane cryostat.

5.10.3. A set of documentation shall be prepared per FESHM 5032, *Cryogenic System Review* to demonstrate to the review panel that aspects of the membrane cryostat cryogenic system, which could present a hazard to equipment or personnel, have been examined.

5.10.4. Approved engineering notes shall be filed in Teamcenter.

- a. A New Item shall be created in Teamcenter with the type chosen as Engineering Note.
 - i. The New Item Name shall use the Membrane Cryostat prefix followed by a meaningful Name which briefly describes the contents of the note.
 - ii. A full Description shall be entered for the New Item.
- b. If applicable the Division Legacy Number shall be entered.
- c. The appropriate Engineering Note category of Membrane Cryostat shall be chosen.
- d. The Revision Author, Revision Comments, Lab Location Code, Exceptional Status, and Division\Section\Project shall be entered.
- e. The Engineering Note and supporting files shall be added as Data Sets. All documentation required for independent review of the Engineering Note must be included.
- f. Approval
 - i. The Teamcenter Workflow may be used to electronically obtain the required

- approvals and release the Engineering Note.
- ii. Approvals may also be obtained by physical signature, scanned, and included with the Engineering Note. A Teamcenter Workflow must still be completed so that the Engineering Note is released. This workflow need not involve the required approvers in the case of physical signature.
 - g. Amendments to existing Engineering Notes shall be entered as a Revision to the original Item in Teamcenter.

5.11 *Reviews:*

5.11.1. All required Engineering Notes shall be reviewed by the Cryogenic Safety Panel.

5.11.2. The associated cryogenic system shall be reviewed by the Cryogenic Safety Panel per FESHM 5032, including solutions for preventing and mitigating spills of liquified gas into enclosures.

5.12 *Modifications to a compliant system:* Any subsequent changes in usage or operation of a membrane cryostat (already in compliance with this chapter) shall meet the requirements of this chapter. Significant modifications impacting system safety shall be documented in a reviewed Amendment to the original Engineering Note.

5.13 *Director's Exception:* Exception to the provisions of this chapter shall be allowed only with the approval signature of the Laboratory Director or designee and the Chief Safety Officer or designee and documented in the Engineering Note. The need for such exceptions is to be minimized by adherence to the provisions of this chapter. Exceptions are to be identified and submitted to the Director for review as early in the design process as possible. These exceptions shall only be allowed after the Director is assured that sound engineering practice will be followed during design, fabrication, erection, quality control, testing, maintenance, repair, and operation of the equipment covered by this chapter.

6.0 ENGINEERING NOTE

An Engineering Note shall follow format of the FESHM 5031.7TA “*Metallic Membrane Cryostat Low Pressure Vessel Engineering Note Form*”. Its purpose is to allow a reviewer to check the design, allow a reviewer to document the completion of the requirements of this chapter and “*Requirements*”, and to inform a future user of the appropriate vessel parameters. An Engineering Note shall include documentation per requirements shown in Section 5.10 above and in Section 9 of the “*Requirements*”.

7.0 REFERENCES

1. 10CFR851 Worker Safety and Health Plan
2. Fermilab Worker Safety and Health Program ESH Section DocDB #250
3. Fermilab Engineering Manual

4. Japanese Gas Association Recommended Practice 107-02 (JGA RP-107-02) “Recommended Practice for LNG Inground Storage”
5. British Standard BS EN 14620 “Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0°C and -165°C”
6. American Society of Civil Engineers ASCE 7 “Minimum Design Loads for Buildings and other Structures”
7. ANSI/AISC 360 “Specification for Structural Steel Buildings”
8. EN1993 “Eurocode 3: Design of steel structures”
9. ACI 318 “Building Code Requirements for Structural Concrete and Commentary”
10. ASME Boiler and Pressure Vessel Code
11. API 520 “Sizing, Selection, and Installation of Pressure-Relieving Systems”
12. API 521 “Guide for Pressure-Relieving and Depressuring Systems”
13. API 2000 “Venting Atmospheric and Low-Pressure Storage Tanks (Nonrefrigerated and Refrigerated)”
14. CGA s-1.3 “Pressure Relief Device Standards Part 3 Compressed Gas Storage Containers”
15. EN 13480 “Metallic industrial piping”
16. Pacific Northwest National Laboratory PNNL-18696, 2009 “Pressure Systems Stored-Energy Threshold Risk Analysis”
17. FESHM 2110 “Ensuring Equivalent Safety Performance When Using International Codes and Standards”
18. FESHM 5031.4 “Inspection and Testing of Relief System”
19. FESHM 5031.7 Technical Note “Requirements for the Design, Fabrication, Erection, Installation and Testing of Metallic Membrane Cryostats”
20. FESHM 5031.7 Technical Appendix “Technical Appendix Form (TA5031.7) For Membrane Cryostats Engineering Note Per Chapter 5031.7”
21. FESHM 5032 “Cryogenic System Review”
22. FESHM 6010 “Fire Protection Program”